Computational Engineering and Physical Modeling 5-4 (2022) 102-112

Contents lists available at **CEPM**

Computational Engineering and Physical Modeling

Journal homepage: www.jcepm.com

Probabilistic Analysis of Bearing Capacity with the Pressuremeter Method

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https://doi.org/10.22115/CEPM.2023.353822.1218

ARTICLE INFO

Article history:
Received: 28 July 2022
Revised: 10 June 2023
Accepted: 11 June 2023

Keywords:
Normal law;
Bearing capacity;
Pile;
Reliability;
Pressuremeter test.

ABSTRACT

The evaluation of the bearing capacity of shallow or deep foundations is a major and traditional problem This article deals with the estimation and analysis of this bearing capacity but with a probabilistic method (statistics) therefore the main objective of this work is to do a probabilistic analysis. To answer and achieve this goal, the work has two lines of research: a theoretical one which brings together a bibliographical synthesis on the estimation of the bearing capacity of a pile by the in situ method (in place) such as the pressuremeter test and the second axis is experimental reinforced by a statistical analysis. The results of the pressuremeter test used in the evaluation (determination) of the bearing capacity of a pile considered as a deep foundation which actually represents the abutment of a rail bridge. An experimental study is underway for pressuremeter test on several sites. The geotechnical data comes according to a study of the project for the construction of a deep foundation for a bridge in the region of Tissemsilt in Algeria, after having defined the pressuremeter profile and estimated the bearing capacity by the pressuremeter method, the reliability of the results was tested. by a probabilistic (statistical) analysis using the normal distribution.

How to cite this article: Houari O. Probabilistic analysis of bearing capacity with the pressuremeter method. Comput Eng Phys Model 2022;5(4):102–112. https://doi.org/10.22115/cepm.2023.353822.1218

Notations

δ	Angle of friction between the ground and the pile (δ =2 /3φ)
S_r (%)	Degree of saturation
D	Diameter of the pile
γ_s	Dry density
p_{le}	Equivalent limit pressure
p^*_{le}	Equivalent net limit pressure
A	Lateral surface of the pile
L	Length of the pile
k_p	Lift factor
P_{LIM}	Limit pressure
q_l	Limit pressure under the tip
W_L(%)	Liquidity limit
K	Normal stress to the pile / stress parallel to the axis at depth z
P	Perimeter
I_P (%)	Plasticity index
E_M	Pressuremeter module
$\boldsymbol{p_f}$	Probability
$\boldsymbol{F(\frac{m}{\sigma})}$	Probability density function
S	Section of the base of the pile
σ	Standard deviation
m	The mean
q_s	Unit lateral friction at z-depth
γ	Volume weight
W(%)	Water content
γ_h	Wet volume weight

1. Introduction

The realization of the deep foundations of the structure as the bridges mocks. is becoming easier to achieve through the development of performance technologies, as well as to evaluate the bearing capacity of this type of foundation, there are several method to evaluate this carrying capacity theoretical or classical method [1], the method an empirical one based on the interpretation of the results of in situ tests such as the pressuremeter test [2]. Which is the goal of this work and the third method which are the numerical methods that uses finite element methods based calculation codes [3]. That are beautiful as far as our day goes thanks to computer-based development and the progress of behavioral model.

The main objective of this paper is to make a probabilistic (statistical) analysis of the limit pressure results and bearing capacities of a pile through the experimental approach and to test the reliability of the results using a normal law. (Gaussian distribution).

2. Theoretical synthesis

The deep foundations are those which allow the loads due to the structure they support to be carried over layers lying from the surface to a depth varying from a few meters to several tens of meters, [4]. (when the surface soil does not have sufficient strength to support these loads through superficial foundations For deep foundations, the way of working and the interaction with the surrounding soil lead to the introduction of the notion of critical depth [5] in this work we mainly present the methods for determining the bearing capacity of piles based on the results of pressuremeasures tests and classical methods.

3. Classical methods

A foundation is intended to transmit to the ground, under the most favorable conditions. The loads coming from the superstructure (Fig 1). The classical theories of the calculation of the axial limit load of a pile are based on the hypothesis of the rigid behavior. soil plastic, assumed everywhere in a state of rupture in a certain zone around the pile In these theories, unit resistant forces (Tip resistance (q_l), lateral friction limit (qs)) depend only on the characteristics of soil failure measured in the laboratory (cohesion c and angle of friction φ) and are directly related to the depth (via the vertical stress σz due to the weight of land above the level (z) considered) [6].

$$Q_l = (A.q_s)/2 + (S.q_l)/3 \tag{1}$$

Term of the tip

$$q_l = \gamma.N_\gamma.R_m + \gamma.D.N_q + c.N_c \tag{2}$$

Side friction term

$$f_s = k\sigma_v^{'}(z)\tan(\delta) + \beta.c_u(z) \tag{3}$$

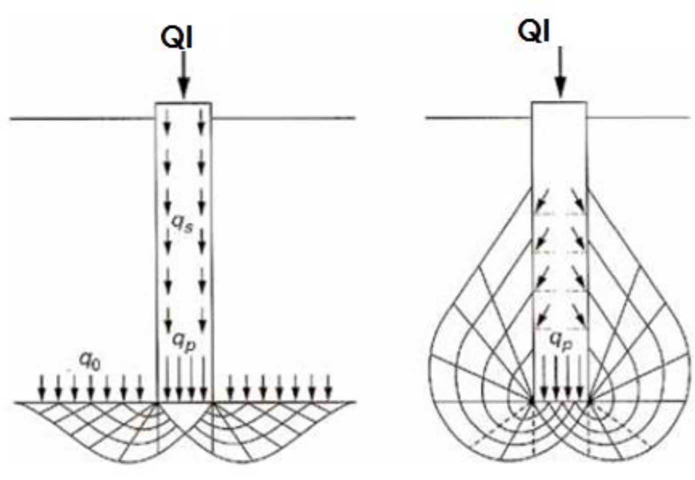

Fig. 1. Examples of break patterns according to classical theories [7].

3.1. Pressuremeter method

The pressuremeter invented by Louis Menard (1955 and 1959) is a device widely used today in foundation projects. Its use is widely extended thanks to the work of Michel Gambin (1963 and 1979). This test consists in carrying out the horizontal expansion of a cylindrical probe in a borehole at a given depth, under radial stresses until the rupture of the ground. It makes it possible to obtain a relationship between the applied stresses and the horizontal displacements of the drilling [8][4] [9][7][10][11][12][3][13].

The test makes it possible to determine two parameters

- The pressuremeter module (E_M): used to determine the settlement of foundations
- The limit pressure (P_{LIM}): which corresponds by definition to the rupture of the ground, intervenes in the calculations of stability of the foundations (the carrying force of the superficial foundations)

3.1.1. Pressuremeter design

Fig.2 shows the composition of the Ménard pressuremeter which includes: the probe and the control unit, called (pressure-volume controller), abbreviated as CPV. These two parts are connected by semi-rigid tubes of plastic [13].

3.1.2. Pressure gauge probe

It consists of three independent cells, mounted around a metal core:

-Central cell, called measuring cell, which contains water and whose pressurization during the test causes the volume variation;

-Two guard cells, which contain gas and which frame the measuring cell; the pressurization of the guard cells under test is carried out simultaneously with that of the measuring cell, so as to maintain the generally cylindrical shape of the probe, thus the deformation of the measuring cell is only radial and the Pressuremeter test is a plane strain test [4]. The mode of deformation of the pressuremeter probe, the main characteristic is the limit pressure (P_{lim}), (Figure 2).

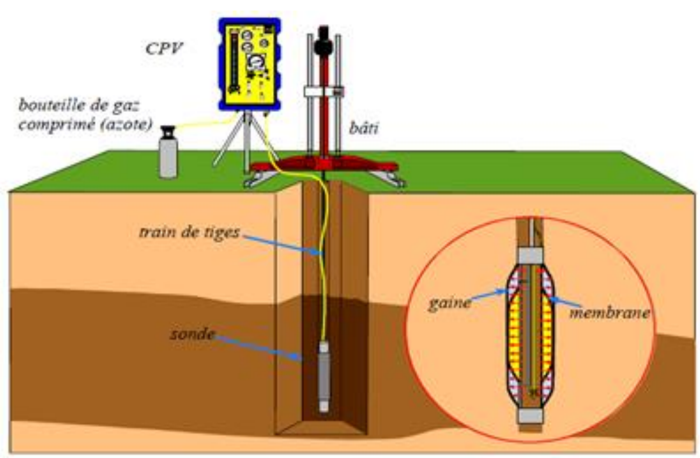

Fig. 2. Procedure of the pressuremeter test [12].

Which corresponds to the rupture of the ground, in the calculations of stability of the foundations for a homogeneous ground Menard calculates the Stress of rupture is given by the following expression (4) [6]: The breaking stress is given by the following expression:

$$q_l = k_p . p_{le}^* \tag{4}$$

The equivalent net limiting pressure characterizing the compactness of the soil in the vicinity of the tip (Figure 3) was calculated from the following general expression:

$$p_{le}^* = \frac{1}{3a+b} \int_{L-b}^{L+3a} p_{le}(z) dz \tag{5}$$

$$\begin{cases} a = \dfrac{B}{2} & if\ B > 1m \\ a = 0.5\ m & if\ B < 1m \end{cases}$$

b = min (a;h)

h: The height of the foundation in the carrier layer

a ,b and h are defined in Figure 3.

The frictional resistance of the piles was calculated from the following general expression:

$$q_s = \pi . B \int_0^L q_s(z) dz \tag{6}$$

The unitary lateral friction limit of the piles was read on the chart of Figure 4 depending on the implementation mode of the pile, the nature of the soil and the limit pressure P_l measured in the soil. Classes A, B and C of the soils were a function of the limit pressure in the field (Table 1).

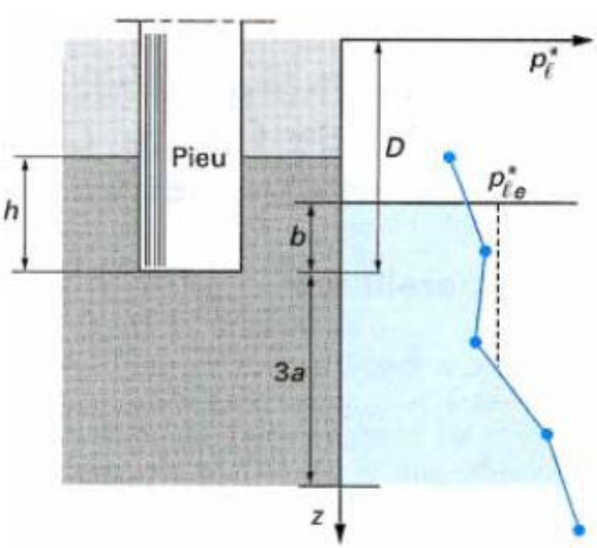

Fig .3. Definition of the pressure-limit equivalent to the pressuremeter [7].

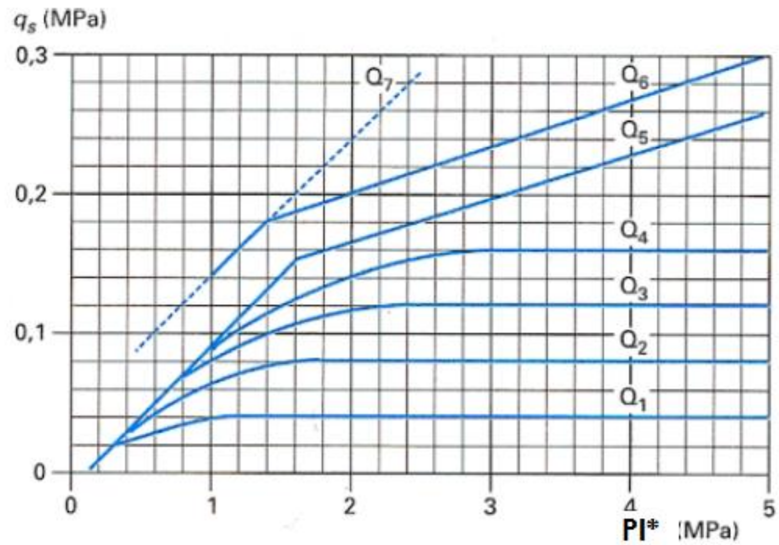

Fig. 4. Limited lateral unitary friction along the shaft of the pile [7].

Table 1
Summarizes the Lift coefficient Kp [7].

		Soil type	P_l (MPa)	k_p	implementation mode of the pile
Clays. Silts	A	Soft clays and silt	< 0,7	1.1	Q_1
	B	Clays and firm limes	[1,2 -2,0]	1.2	Q_2
	C	Very firm to hard clays	> 2,5	1.3	
Sands. Graves	A	cowards	< 0,5	1.0	Q_3
	B	Moderately compact	[1,0- 2,0]	1.1	
	C	Compact	> 2,5	1.2	

4. Materials and methods

To meet the objectives quoted above, a set (series) of pressuremeter tests has been carried out. The type used is the Ménard pressuremeter, which consists of horizontally expanding a cylindrical probe in a borehole at a given depth. under radial stresses until the ground breaks.

And who gave us a better reader and speed of results that gave us the different pressuremeter features namely: limit pressure, creep pressure and so the pressuremeter module. Four (04) sites were used in this study where surveys were conducted to provide a visual description of the surface-mounted samples that denotes a formation consisting essentially of a silty clay mole surmounted by a greenish gray clay to visually compact the whole is sometimes covered by a heterogeneous embankment and sometimes by a compact gray silty clay plastic the surface complex is provided by a remolded soil. The core drilling conducted at the according to a study of the project for the construction of a deep foundation for a bridge in the region of Tissemsilt (Algeria) show the following lithological succession which are summarized in Table 2.

Survey N ° 01

0.00-0.70m: red clay-sandy limestone backfill

0.7-20.00m: greenish silty clay, locally gypsiferous, compact, soft and very plastic in places, with presence of a passage of gypsum deposit in crystals between 1.60 / 3.00 meter

Survey N ° 02

0.00-1.50m: remolded soil of sandy-clay limestone and greenish clay.

1.5-25.40m: Greenish silty clay, locally gypsiferous, compact, soft and very plastic in places, with presence of a passage of gypsum deposit in crystals between 1.50 / 2.50 meter.

25.40-28.00m: gray marl, compact becoming a moderately indurated base with a laminated appearance.

Survey N ° 03

0.00-0.50m: red clay-sandy limestone backfill.

0.50-20.00m: greenish silty clay, locally gypsiferous, compact, soft and very plastic in places, with presence of a crystal gypsum deposit between 0.50 / 3.00 meters.

Survey N ° 04

0.00-1.10 m: red clay-sandy limestone backfill.

1.10-20.70m: Greenish silty clay, locally gypsiferous, compact, soft and very plastic in places, with presence of a crystal gypsum deposit passage between 1.10 / 1.40 meters.

20.70-28.00m: gray marl, compact becoming a moderately indurated base with a laminated appearance.

Table 2
Set of parameters.

	Depth	γ_h (t/m^3)	γ (t/m^3)	γ_s (t/m^3)	W(%)	W_s (%)	S_r (%)	W_L (%)	I_P (%)
SP1	9.40-9.45	2.03	1.62	2.70	25.55	24.74	100	74.50	43.85
	11.5-12.0	2.07	1.69	2.70	22.28	22.02	99.3	81.40	46.73
	14.1-14.5	2.04	1.65	2.70	23.70	23.57	100	79.10	46.90
SP2	12.2-12.8	2.06	1.67	2.70	23.40	22.82	100	80.90	49.72
	14.8-15.0	2.07	1.69	2.70	22.84	22.21	100	83.60	51.92
SP3	2.60-3.00	2.00	1.54	2.70	29.56	27.79	100	81.35	47.40
	15.3-18.8	2.07	1.68	2.70	23.43	22.60	100	78.40	46.11
SP4	4.80-5.00	2.025	1.64	2.70	24.58	23.68	100	86.30	53.12
	7.00-7.30	1.05	1.64	2.70	24.58	23.68	100	83.60	51.92
	11.7-12.0	2.005	1.61	2.70	24.47	23.91	97.2	77.65	46.11
	14.7-15.0	2.08	1.70	2.70	21.96	21.57	100	81.20	47.35

5. Results and discussion

At the end of the tests, the profile of the limit pressure figure5 used later in the estimate of the bearing capacity for the 10 m and 0.6 m diameter piles was determined. Several results were found to test the reliability of the results. to find a probabilistic (statistical) study we have chosen two methods, the method of the histograms of the parameters concerned (limit pressure and the carrying capacity of a pile, and the second method consists of using Gaussian distribution which gives the expression (7) with m represents the mean and sigma represents the standard deviation of the sample, in order to check the dispersion of the results for the same work site consequently the reliability of a test in comparison with the histogram method, the ideal situation is the closest to the random Gaussian distribution $X\,N$ (m, σ) [11]:

$$f_X(X) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{(X-m)^2}{2\sigma^2}\right] - \infty < X < \infty \quad (7)$$

Figure 6 shows the graphical representation of Gaussian profile and the histogram of the evolution of the limit pressure and even for the figure7 for the bearing capacity at the base of a pile, approach to the ideal situation one tests the reliability of the results one uses the formula represents in equation (8) for a normal distribution form [14].

$$p_f = 1 - F(\frac{m}{\sigma}) \quad (8)$$

With p_f represented the Probability and $F(\frac{m}{\sigma})$ represented probability density function this value was estimated based on the Gaussian distribution tables. So the Table 3 summarizes all the results and we see that the results are all reliable, we can find a correlation between the limiting pressure and the bearing capacity and these correlations are valid only for this study.

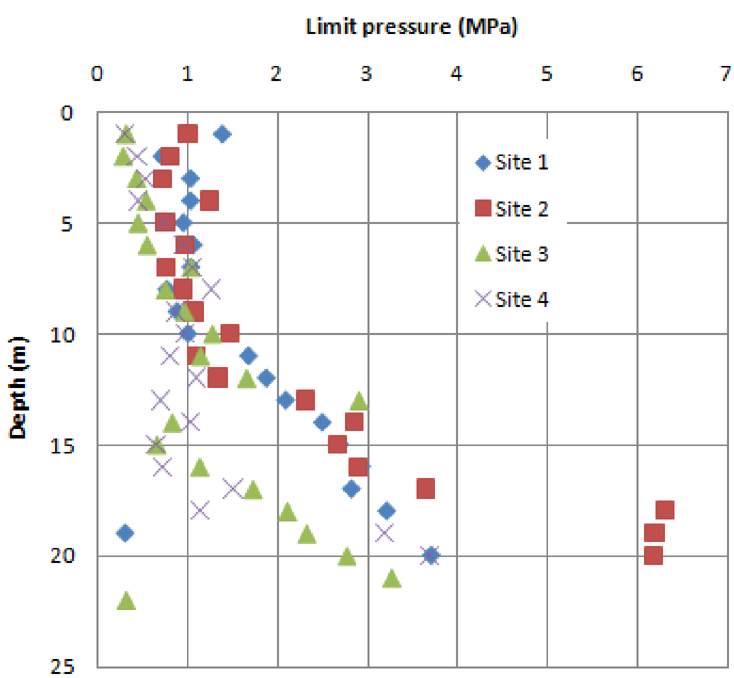

Fig. 5. Limit pressure profile.

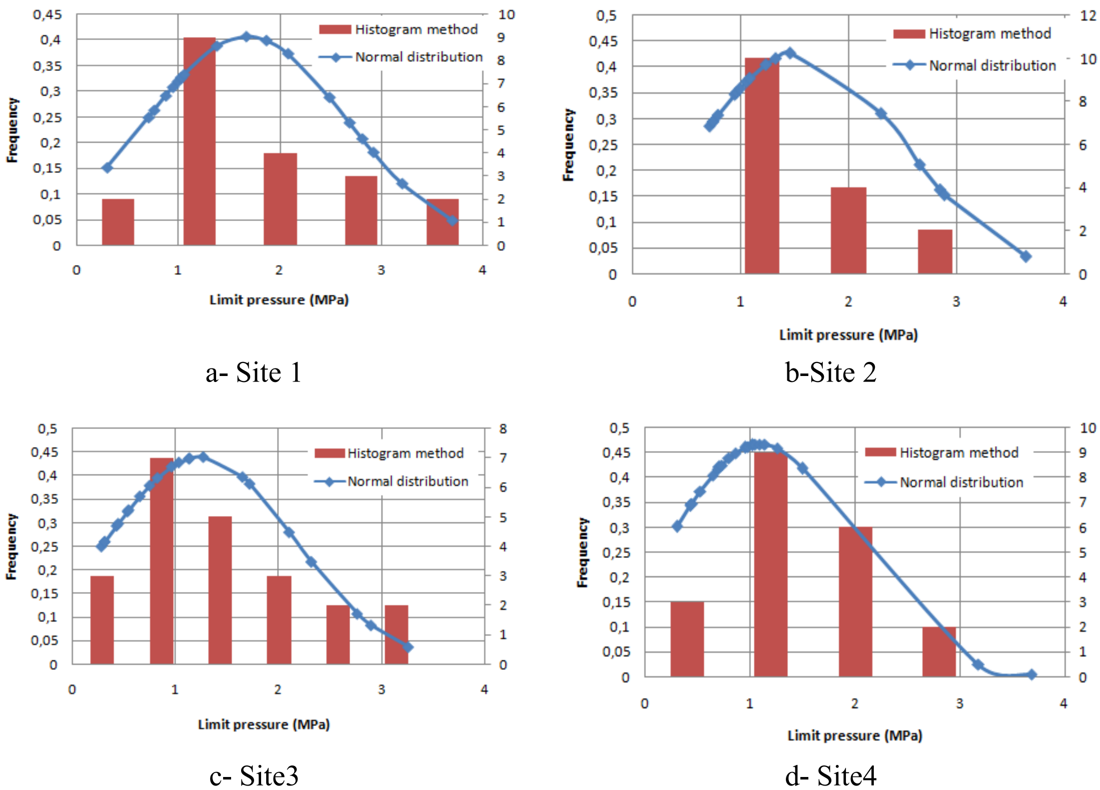

Fig. 6. Distribution of the limiting pressure.

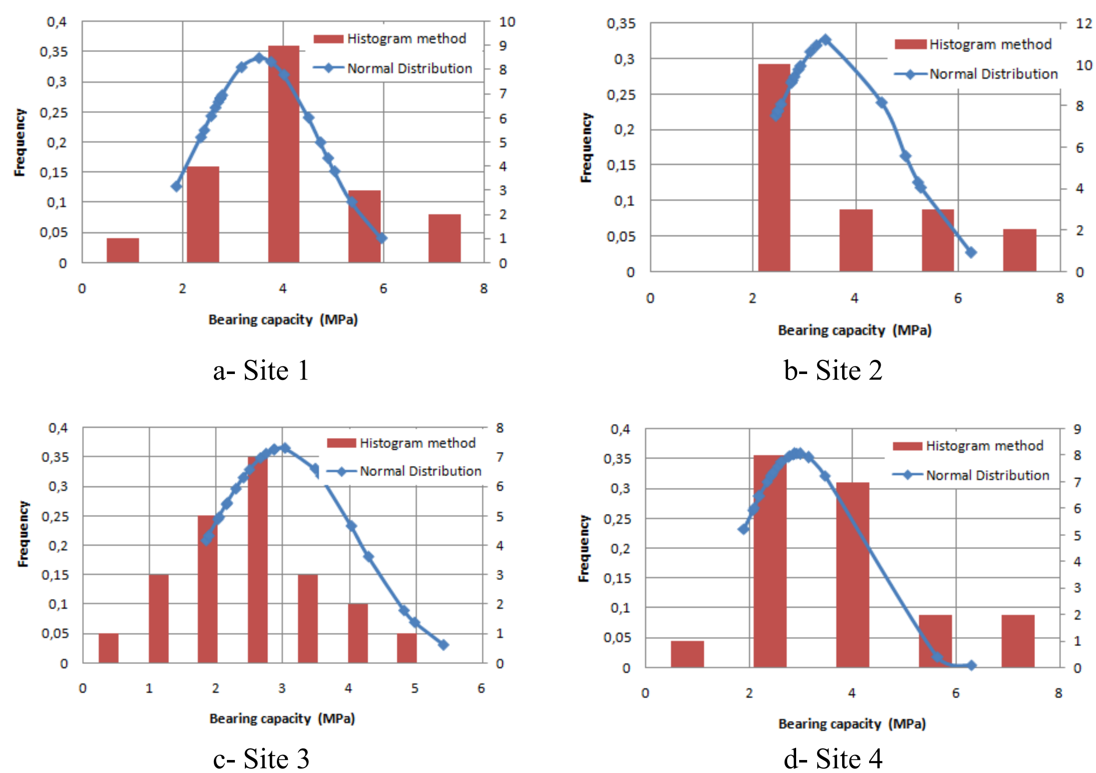

Fig. 7. Distribution of the values of the bearing capacity.

Table 3
Summarizes all the results.

		Pressuremeter test		Bearing capacity	
		Limit pressure	Probability p_f	Bearing capacity	Probability p_f
Site 1	m	1,67	P_f=1-F (1,7063)	3,51	P_f=1-F (2,99)
	σ	0,98	P_f=4,46 (%)	1,17	P_f=0,14(%)
Site 2	m	1,55	P_f=1-F (1,67)	3,52	P_f=1-F (2.91)
	σ	0,93	P_f=4,75(%)	1,21	P_f=0,19(%)
Site 3	m	1,24	P_f=1-F (1,37)	2,99	P_f=1-F (2.75)
	σ	0,91	P_f=4(%)	1,09	P_f=0,31(%)
Site 4	m	1,09	P_f=1-F (1,28)	2,93	P_f=1-F (2.63)
	σ	0,85	P_f=5(%)	1,11	P_f=0,41(%)

6. Conclusions

In this study, the problem of estimating the bearing capacity of a foundation has been dealt with by the in situ method using the probabilistic method (statistics) and we have based it on two lines of research, one theoretical (one bibliographic analysis) and the other mathematical analysis (statistics) is we found the following points:

- The limit pressure is influenced by the nature of the soil
- The limiting pressure is influenced by the method of execution of the test
- The variation of the bearing capacity is influenced by the variation of the limit pressure and the geometry of the pile
- The normal law is the best test for the reliability of the results found

It is clear that this result still needs improvement in order to make practical conclusions in relation to the practice.

Conflicts of interest

The author declare no conflict of interest.

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